Remote Survey of a Near-Coastal Archaeological Alignment at Kualoa, Hawai'i Using Worldview 2 Satellite, LiDAR and UAV Imagery

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Abstract

By using World View 2 multispectral satellite imagery, LiDAR, and unmanned aerial vehicles, a large submerged archaeological stone alignment, that is likely part of an ancient Hawaiian fishpond, was detected off the coast of Kualoa, Hawai'i during a remote survey of the area. Principal component analysis, ratio indices, and LiDAR interpretation were utilized in a GIS to help detect this archaeological stone feature that is located in shallow coastal waters. Because threats of modern development, sea-level fluctuations, and complications inherent to coastal-maritime environments have generally challenged the survey of cultural resources located within the coastal strand, this method holds promise for future spatial analyses and provides an accessible and cost efficient means of shoreline assessment. This paper aims to show how remote sensing methods can assist in the study of archaeological features that are located within difficult to access coastal and near-coastal areas.

Key words: Remote Sensing, Coastal Survey, Fishponds, Archaeology, GIS

Introduction

On the windward side of the island of O'ahu, an archaeological alignment was detected utilizing remote sensing techniques in the near-shore coastal flats of the northwest section of Kane'ohe Bay near Kualoa Regional Park. Kualoa is a culturally significant *ahupua'a* (land division) with a rich, traditional prehistory associated with social elites of old Hawai'i and today it is maintained by the City and County of Honolulu. Kualoa is also a *pu'uhonua* (ceremonial center) that was governed by the *kahuna nui* (high priests) of Hawai'i who maintained close relationships with the neighboring watersheds of Hakipu'u on the west and Ka'a'awa on the north as seen in (Figs.1-2) (Sterling and Summers, 1962; Gunness, 1987). Traditionally, these land divisions possessed stone-walled fishponds that were typical of an intensified form of aquaculture practiced in early Hawai'i (Kikuchi, 1976). However, the spatial data that exists on this subject matter is limited. Accordingly, this paper provides an efficient means of surveying submerged, archaeological features located in shallow, coastal waters using satellite, LiDAR and digital camera imagery.

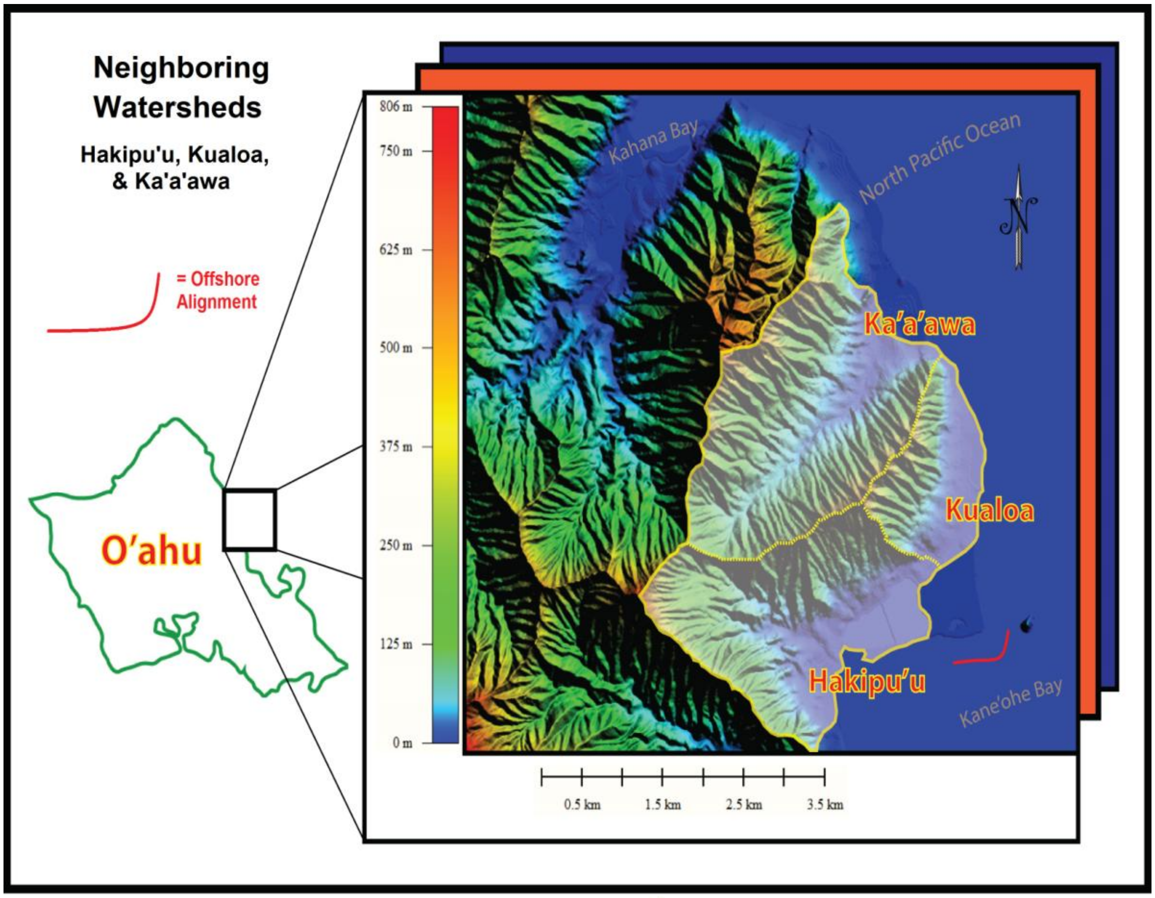

Fig. 1 Area on O'ahu, Hawai'i Where Offshore Stone Alignment Was Detected. (Damion Sailors, 2013)

The Site Location - Kualoa

The first archaeological survey of Kualoa was performed by J. G. McAllister in 1933 and included the documentation of Mōli'i fishpond, 'Āpua Pond, Mokoli'i Pond, Koholālele Pond, and Niuola'a Heiau. McAllister learned through interviews and translations that Kualoa is a *pu'uhonua* (ceremonial center) where large ceremonies dedicated to *Lono* (the god of harvest) were performed and that the area was also well-known for its association with ancient Polynesian genealogies. Kualoa is also respected for its ancient burial caves reserved for social elites and its unique access to *palaoa* (sperm whale ivory) which, because of its wealth, afforded Kualoa political power in precontact Hawai'i (Gunness, 1987). McAllister also collected a reference from a local informant about an ancient fish pond named Pilihe'e that was destroyed by a tsunami sometime prior to the mid-19th century (Sterling and Summers, 1962). This fishpond was then located and mapped during a student pedestrian survey during the Kualoa Archaeological Research Project (1975-1985) using a rough "tape and compass" method but was not explored further. As a consequence, this fishpond is not well-known in either academic or local communities and management of this archaeological resource has not occurred (Gunness, 1987; Carson and Athens, 2007).

Fig. 2 Aerial photograph of Kualoa Beach Park taken from an airplane showing Mōli'i Pond (large pond on left) and 'Āpua Pond (small pond on right), shoreline accretion at south end of Kualoa, and coral reef development in area. (John O'Connor, 2013)

There have been other, more recent archaeological studies conducted at Kualoa Park, and to summarize the findings thus far, there have been 44 shoreline burials recovered to date and a large amount of material artifacts consisting of large proportions of basalt tools, *kapa* (bark cloth) making utensils, and gaming stones. The recovery of these artifacts support the inference that Kualoa was a ceremonial center associated with the *Makahiki* festivals honoring the god *Lono.* Interestingly, fishing gear was poorly represented (only 3.62% of total artifacts) as were household items (2.89%) (Barrera, 1974; Gunness, 1987). The survey of this offshore alignment at Kualoa is significant because of the wall’s probable antiquity and what it might add to the overall anthropological discussion regarding maritime coastal adaptation in an island environment (Kikuchi, 1976). The absolute age of this feature is unknown but because this stone alignment is of substantial size, it can be inferred that an organized social effort was invested in its construction and maintenance (Kirch, 2010). Oral traditions and geomorphological studies also support the idea that Kualoa was not only a sacred land-division with an extensive royal history, but that it was particularly vulnerable to damage from tsunamis that periodically strike the islands (Gunness, 1987; Carson and Athens, 2007). Considering that the coastal zone of this windward part of O'ahu is highly dynamic in terms of its coastal geomorphology, this stone wall may have also served as a type of break-water constructed in an effort to modify the coastline or it may have functioned as an aggregate for fishing (Kikiloi, 2003).

Pacific Island Fishponds

At the time of Captain Cook’s arrival to Hawai'i in 1778 there were an estimated total of 360 fishponds of varying size and function located throughout the archipelago. On average, these fishponds were each thought to have produced a total of 3000 kg of fish per year (Kikuchi, 1976; Kikiloi, 2003). At first, this may seem rather industrious, but if we consider that the population in old Hawai'i may have conservatively been around 300,000 people, there would have been very little fish to go around (Schmitt, 1971; Wyban and Wyban, 1989). It is estimated that fishpond technology in Hawai'i may be at least seven centuries old after results from analyses made of the Alekoko and Kekupua Ponds on Kaua'i revealed a radiocarbon range from 1140 - 1280 AD (Burney and Burney, 2003). This is the oldest radiometric evidence there is for fishpond use in Hawai'i but it is possible that the origin of this technology extends further back in time. Hawaiian fishpond types can be separated amongst those that are dependent upon freshwater, brackish water, and seawater. The primary fish harvested in Hawaiian fishponds were mullet and milkfish and at least 22 species of edible marine life also flourished in these ponds as secondary domesticates (Kikiloi, 2003). Based on the available evidence, it could be argued that in contrast to the rest of Oceania, the Hawaiian Islands claimed a more sophisticated aquacultural system (Kikuchi, 1976). This argument is bolstered by the apparent large numbers of fishponds in Hawai'i, their larger acreage, variation in the types of sites, and in the technological complexity of the system. However, there is evidence that other areas such as in the Society Islands, Micronesia, and Western Polynesia, fish pond technologies were just as elaborate and intensified as those found in Hawai'i (Dieudonne, 2002).

Remote Sensing methods

The advancements in both passive and active sensors used in remote sensing allow for the collection of data or imagery with greater spatial, temporal, spectral, and radiometric resolution. One example of advancements made with passive sensors is the multispectral sensors on board some of today's satellites (World View 2, Landsat MSS, IKONOS). Multispectral sensors break up the electromagnetic spectrum into multiple bands allowing for a finer analysis of an object's reflectance value than previous sensors. Hyper-spectral sensors allow for an even finer analysis, breaking up the electromagnetic spectrum into hundreds of spectral bands (Jensen, 2005). Also an active sensor technology that has seen increasing use is LiDAR (short for light and radar). LiDAR is useful in detecting changes in elevation of an area at a relatively high resolution. The Worldview 2 satellite is a commercial satellite that was launched in 2009 and is capable of collecting 8-band multispectral imagery at a high resolution with an average revisit time of 1.1 days. The spatial resolution of the images is 1.85 m for the 8-band multispectral images and 0.46 m for the panchromatic image. There are 8-bands that the satellite groups into different parts of wavelengths (nm) within the electromagnetic spectrum. The 8-bands and sections are the coastal band (400 - 450 nm), blue band (450 - 510 nm), green band (510 - 580 nm), yellow band (585 - 625 nm), red band (630 - 690 nm), red edge (705 -745 nm), near-infrared 1 (770 - 895 nm), and near-Infrared (860 - 1040 nm) (Digital Globe, 2013). Since each band collects at different sections of the electromagnetic spectrum, each band can contain different information based on the material an object or feature is made of. Each band also interacts differently with water. The least amount of absorption and scattering takes place in the wavelengths between 400 - 500 nm. Thus the two lowest bands, the coastal band and blue band, are the most suitable bands to detect underwater features. In contrast, the wavelengths represented by the red and near-infrared bands are highly absorbed by water (Jensen, 2007). In passive remote sensing techniques, there are multiple operations that can be done to multispectral satellite imagery in order to produce analyzable results.

Processing

The first process tree began by pan-sharpening the satellite imagery. Pan-sharpening was done so the multispectral bands could have a higher resolution of the panchromatic band, which was 0.46 m (Padwick, 2010). The terrestrial areas were then masked out of the image. This was done to ensure that the full range of digital numbers in the imagery belonged to pixels of offshore areas which could then be analyzed with greater detail. An index ratio called the non-homogenous feature difference (NHFD) was then performed. The NHFD takes the red-edge and coastal bands into the following formula: (red-edge - coastal) / (red-edge + coastal) (Wolf, 2010). Index ratios, such as the NHFD, enhance the contrast between two bands (Zeinelabdeina and Albielyb, 2008). The reason why this formula works well in detecting offshore features is because the red-edge and coastal bands interact with water very differently. The energy in the spectrum of the red-edge band is highly absorbed by water where the energy in the spectrum of the coastal band is not. When two bands have very different reactions to a phenomenon (e.g. water) the ratio of those two bands will usually have a substantial amount of information (Jensen, 2005). This creates an image that visualizes the contrast between objects closer or above the surface of the water to objects towards the bottom of the sea floor.

The second process tree started with the pan-sharpening and masking out of the terrestrial areas of the satellite imagery followed by a principal component analysis (PCA). PCA is an image enhancement technique that transforms the multispectral imagery into principal components (PCs). Each principal component represents the spatially correlated brightness values of each band in the multispectral imagery, while being uncorrelated to other derived principal components. From the 8 multispectral bands, 8 PCs are derived. The first PC will have the most information and the last PC will usually have the least. The goal of PCA is to reduce the amount of spatially repeated data throughout the 8 bands of the multispectral imagery into principal components that are quite easy to interpret (Jensen, 2005). Once PCA was executed, PCs 1 and 2 were visualized in the GIS platform well-known as ArcMap.

LiDAR has the ability to gather elevation data on land and the bathymetry of areas in shallow waters with relatively high accuracy (Jensen, 2007). LiDAR, that was made available through the 2013 National Science Foundation - Research Experience for Undergraduates, was also utilized to help detect the Kualoa fishpond wall. A LiDAR point cloud (0.25 m resolution) was used to create a continuous surface or bathymetric image using Inverse Distance Weighted and Natural Neighbor tools in ArcGIS (Bolstad, 2012). 3D geovisualization in ArcGIS of the LiDAR point cloud readily displayed the shape of the offshore feature. To visualize the point cloud in 3D, graduated colors based on the Z (elevation) value were first given to each point. Then the point cloud was exaggerated to 30 times of its Z value, to best show the variation in depth of the offshore area.

Unmanned aerial vehicle (UAV) technology was also utilized to collect imagery of the offshore feature. Although there are many UAV platforms available, a DJI Phantom Quad-Copter was used as it was made available via the National Science Foundation-Research Experiences for Undergraduates program mentioned previously. A Pentax Optio camera was attached to the Phantom to collect imagery. Due to the weight of the camera, the flying time of the UAV was limited to approximately two minutes. The UAV coupled with the camera allowed for up-to-date imagery within the visible light spectrum of the feature. However, there were some difficulties with the UAV/Pentax combo. The first difficulty was the manipulation of the UAV's elevation and position to ensure that useful imagery over the correct feature was being acquired. Another difficulty was that the Pentax captures imagery only in the visible light spectrum, so in order for submerged features to be detected, a substantial amount of sunlight is needed (P. Nesbit, Personal Communication 2013). Unfortunately, because the weather was uncooperative, only a limited amount of useful images were acquired in the time allotted.

Finally, an underwater pedestrian survey shown in (Fig. 3), using snorkel gear and underwater cameras, was also performed at a high tide in order to visually inspect, measure, and photograph this feature. The wall sections observed on this day were heavily encrusted with coral, algae, and other marine growth, but it was clear that this alignment was indeed a purposefully constructed stone wall of some sort. Its function though remains speculative.

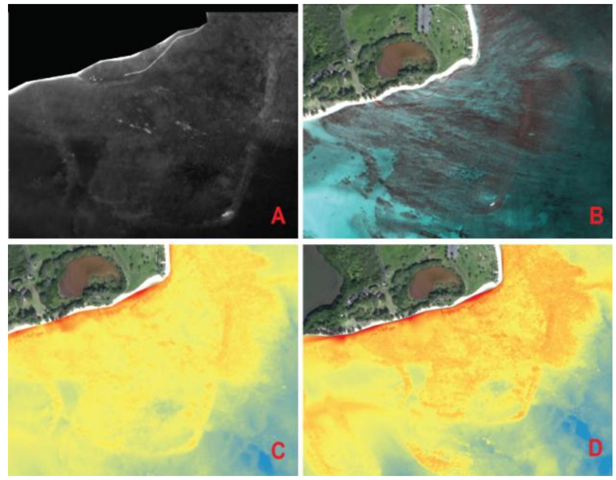

Fig. 3 (left) Underwater survey of offshore alignment at Kualoa Beach Park. Basalt stones used in the wall's construction are heavily encrusted with marine growth but can be easily discerned as an articulated feature. (Chuck DeVaney, 2012)

Fig. 4 (right) Imagery from the steps taken in two "process trees" used to discern the offshore alignment. A) Non-Homogenous Feature Difference (Red-Edge - Coastal) / (Red-Edge + Coastal), B) Principal Component Analysis (Symbolized as PC1: Green and Blue, PC2: Red), C) Inverse Distance Weighted interpolation of LiDAR point cloud, D) Natural Neighbor interpolation of LiDAR point cloud. (Scott Honda, 2013)

Results

Due to the combination of difficulties in maneuvering the UAV, the varying availability of sunlight, and the changing tides, the number of useful images captured by the UAV/Pentax was limited. Given more flying time, stable conditions, and additional equipment, like a field of view camera mounted to the UAV, more useful imagery could have been attained. However, a mosaic was attempted in PhotoScan and Microsoft ICE of the collected UAV/Pentax imagery. Although PhotoScan is capable of producing an accurate and georeferenced image, it could not produce a mosaic image from the collected UAV/Pentax imagery. Microsoft ICE was able to create a mosaic using some of the images taken via UAV, but the resulting mosaic had no ground control points available in the imagery that were usable for georeferencing. The software used for manipulating and visualizing the data for analysis was ERDAS Imagine and ArcGIS. ERDAS Imagine is image analysis software that has the ability to execute many remote sensing and image analysis techniques (Intergraph, 2013). Principal component analysis, ratio Indices, pan-sharpening, and masking of the satellite multispectral imagery were done in ERDAS Imagine. ArcGIS has a variety of tools and applications that can be used to analyze, extract, manipulate, and manage geospatial data but was primarily used for interpolating and visualizing the LiDAR point cloud data.

The image analysis, as seen in (Fig. 4), of this offshore alignment revealed the remnant articulation of a discrete, walled structure that may be part of the aquacultural complex in this area that includes Mōli'i fishpond, 'Āpua Pond, Mokoli'i Pond, and Koholālele Pond. This alignment may be part of the Pilihe'e fishpond mentioned by local informants in McAllister's early twentieth century survey. Alternatively, it may be part of some sort of antiquated breakwater or fish aggregation device placed there long ago. Further study is required in order to understand more about this feature's origin and function. What we do know from this survey is that this alignment is purposefully constructed from basalt boulders, stones, and pebbles, is approximately 550 m in length, three meters wide, and is less than a meter tall on average being exposed at the lowest of tides when it appears to be part of the natural reef formation of the area. It is a large alignment that if proven to be a fishpond wall, would add many hectares to the traditional aquacultural area of Kualoa. Considering the dynamic nature of Kualoa's shoreline, whether it is due to tsunami, tectonic processes and/or sea-level fluctuations, this feature must have been an important variable in the recent social and geomorphological history of this part of Kane'ohe Bay, O'ahu.

Discussion

Based on the non-homogenous feature difference, the principal component analysis imagery, and the LiDAR point cloud, the use of remote sensing techniques (both active and passive) to locate the offshore wall were useful in mapping this near-coastal alignment. Because only the contrast of the wall from the surrounding reef was being sought after, the NHFD was utilized here with the digital number values of the two bands (coastal and red-edge) to demonstrate this contrast. If one were attempting to derive the health or biomass of vegetation, the use of radiance would be more appropriate (Jensen, 2005). Although more sophisticated UAV systems are available, the hobbyist grade Phantom Quad-Copter was capable of imaging the offshore alignment. The post processing of the UAV imagery in photogrammetry based software like PhotoScan could be a useful method of finding and surveying coastal features.

However, in this case study, not all images were usable in PhotoScan. This is probably due to distortions introduced by water. Perhaps if a multispectral camera, with bands that could penetrate water (i.e. coastal blue) were used, PhotoScan would be capable of creating an orthophoto and a digital surface model of underwater features. Kualoa is an area of chronic erosion and accretion, and has had frequent and intense coastal modifications occur over the course of human occupation in the area. How the ancient people of Kualoa adapted to, and perhaps influenced these changes can be seen archaeologically, and thus remote sensing and survey at a high resolution can assist anthropological endeavors in this region (Hunt and Lipo, 2008). Knowledge then gained may shed light on issues of sustainability and how limited resources, such as those found in the Pacific islands, are managed by complex societies (Ladefoged and Graves, 2000; Erlandson, 2010). In a contemporary context, threats of inundation causing the potential loss of cultural resources in coastal areas are immediate and severe. These cultural resources, in the form of archaeological features, can be identified within the coastal strand using the methods we have discussed here in this report. For future study, questions regarding the automation of extracting linear features from remote imagery as well as improvements on data management can be readily explored. Maritime adaptations may be more easily understood using these spatial methods and considering the accessibility and efficiency of this type of non-invasive technique, we propose further similar survey in coastal-maritime regions.

Acknowledgments

Special thanks go to Drs. Carl Lipo, Suzanne Wechsler, Chris Lee, Matt Becker, and teaching assistants of the 2013 NSF-REU G.R.A.M Field Program, at California State University at Long Beach. We would like to thank Dr. Terry Hunt, University of Oregon and Drs. Christian Peterson and Matt McGranahan, University of Hawai'i at Mānoa. Obligations are extended as well to John O’Connor and Chuck DeVaney for photo contributions. And a final *mahalo* or “thank you” is given to the National Science Foundation (Grant # DGE-1329626) and to those who assisted in reviewing the paper.

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